STABILITY CALCULATION FOR THE SURROUNDING ROCK FOR DESANDER

[UPPER TRISHULI-1 HEP (216MW)]

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中国电建 POWERCHINA Power Construction Corporation of China

FOR APPROVAL

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Upper Trishuli-1 HEP (216MW)

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Content

1 General

1.1 Introduction

The desander basin is about 308m downstream of intake structure. It is divided into three chambers, which are arranged underground and not subject to pressure flow. It is mainly used to settle the harmful particles of the suspended sediment larger than 0.2mm. Each chamber is composed of the upstream gate section, diffusion section, working section, downstream gate section, downstream connecting section, and sediment flushing tunnel.

The working section is arranged in the middle of the desander basin, which is the main chamber for sediment settling. The final recommended working section is 100m long, 10m wide and 9.50m deep. The lower part of the working section is a sediment funnel with a depth of 5.70m and the slope angle on both sides is 59.93°. The bottom sediment-flushing groove is 3.40m wide, 1.2m - 2.20m deep, with a bottom slope of 1.0%, and its end is connected with the flushing branch tunnel.

According to the previous geological information and contractor's interpretation, inter bedded mica schist and quartz-schist are developed / distributed along cavern axis and are assumingly classified as Type II or Type III.

The cross section and initial proposed supports of desander basin are shown in Figure 1-1.

The staged excavation is shown in Figure 1-2.

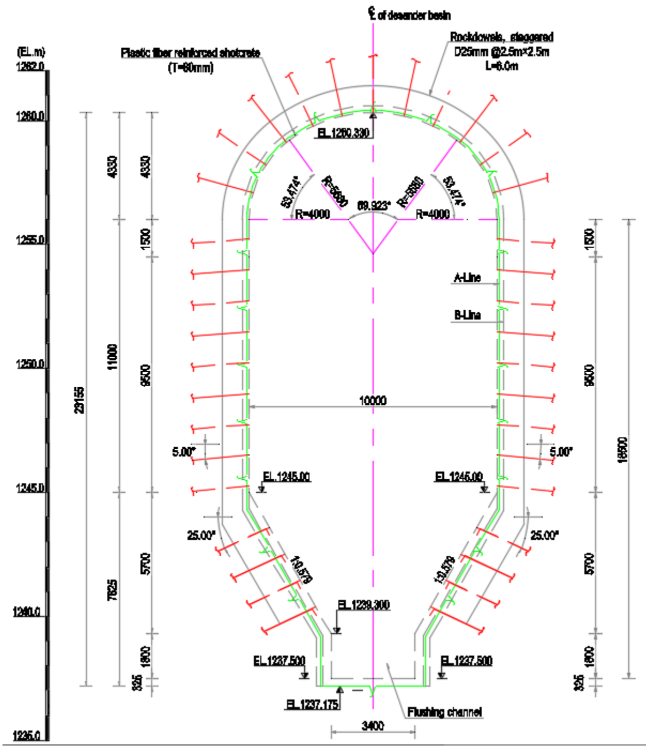

Figure 1-1 Cross section and initial proposed supports of desander basin(rock type II)

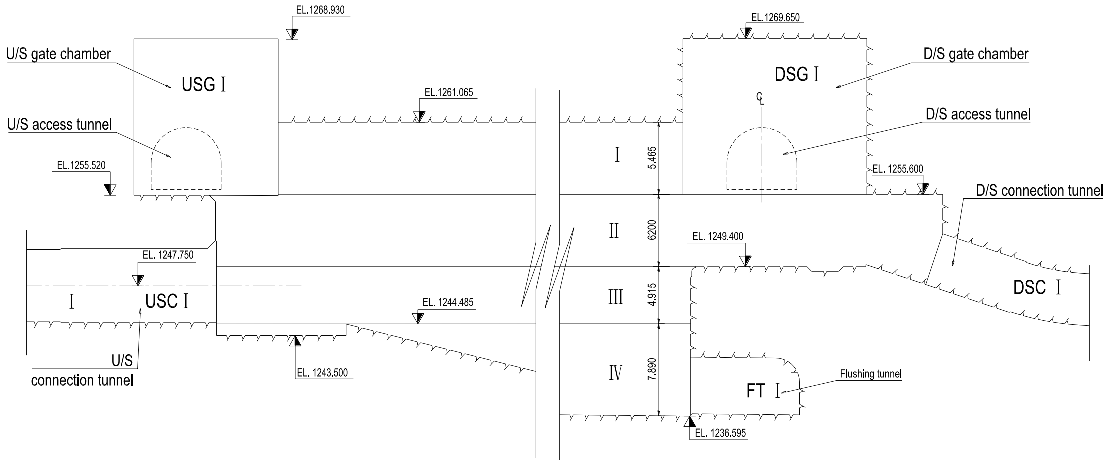

Figure 1-2 Staged excavation of desander basin

1.2 Design Objective

This calculation is aim to verify the proposed supports include rock dowels and shotcrete be effective and feasible; ensure stability of caverns and safety of construction activities during cavern excavation.

1.3 References

(1) Contract documents, Employer's Requirement;
(2) Tunnels and Shafts in Rock (EM 1110-2-2901);
(3) Building Code Requirements for Structural Concrete and Commentary (ACI 318)
(4) Excavation and support drawing of desander basin (Drawing No.: UT1-C-030-CVL-DG-52002).

2 Theoretical Background of Calculations

2.1 Software

Software Phase 2 is applied to conduct the calculation. Phase2 is a powerful 2D finite element program for soil and rock applications. Phase2 can be used for a wide range of engineering projects including excavation design, slope stability, groundwater seepage, probabilistic analysis, consolidation, and dynamic analysis capabilities.

Software UNWEDGE is an interactive software for the stability analysis of three-dimensional wedge formed by structural discontinuity and underground excavation, which is used to analyze the underground excavation problem with discontinuous structural plane in rock mass. UNWEDGE calculates the safety factor of potentially unstable wedge, and can analyze the influence of support system on wedge stability.

2.2 Modeling Conditions, Material Law, Constitutive Model

The modeling conditions are plane strain. The material law is elasto-plastic combined with strain-softening (for rock). The rock mass is modeled as a continuum, homogeneous and isotropic. The failure criteria is the Mohr-Coulomb failure criteria. In reality, the displacements occur in blocky rock masses always along discontinuities (joints, foliation etc.), which leads to loosening of the rock mass. The determined plastic zone in the continuum model represents an area of the rock mass where rock blocks were displaced to each other (= loosening of rock mass). In reality, it does not represent an area where the material was subject to plastic flow, as in soil.

2.3 In situ horizontal stress

For unavailability of field measurement of in situ stresses at the area, gravitational stresses are adopted.

The vertical stress due to the overlying rock is:

$$\sigma_z = \gamma h$$

where γ represents the density that is the unit weight of the rock.

The horizontal in situ stresses also depend on the depth below surface. They are generally defined in terms of the vertical stress as follows:

$$K_0 = \sigma_h / \sigma_v$$

Where K_0 represents the lateral rock stress ratio. Since there are three principal stresses directions, there will be two horizontal principal stresses. In an undisturbed rock mass, the two horizontal principal stresses may be equal.

In this calculation, K_0 is taken as 1.3 according to topographic and geological conditions of the engineering area.

3 Properties of Materials

3.1 Rock Mass

The mechanical parameters of surrounding rock are shown in Table 3-1 as per approval letter RN 0031 but the residual cohesion is taken as 0.5 times of peak value.

Table 3-1 Mechanical parameter for surrounding rock of desander basin caverns

Class of surrounding rock	Q	Unit weight	Poisson's ratio of rock mass	Elastic modulus Of rock mass	Rock mass/rock mass shear (shearing) strength				Uniaxial compressive strength of rock mass	Uniaxial compressive strength of intact rock	Tensile strength of rock mass
					Peak		Residual				
		γ (kN/m^3)	μ	Em (GPa)	*C* *(MPa)*	*Φ* (°)	*Φr* (°)	*Cr* *(MPa)*	UCS rm (MPa)	INTACT UCS r (MPa)	σ_{tm} (MPa)
II	10--40	27.0	0.25	20.5	2.5	48	38	1.25	13.0	60	1.3
III	7--10	26.5	0.25	10.0	1.0	45	35	0.5	4.8	60	0.48

3.2 Rock Dowels

1) Dowel type: cement mortar full length bonded dowel
2) Yield strength: 500MPa
3) Tensile strength: 545MPa
4) Elastic modulus: 210000MPa
5) Allowable tensile strength of rock bolt steel: 500MPa/1.5=333MPa. The value 1.5 is safety factor.

3.3 Shotcrete

The mechanical parameters of plastic fiber shotcrete are shown in Table 3-2. Elastic modulus is calculated by formula Ec=4700*fc'^0.5 (ACI 318, section 19.2.2 Modulus of elasticity).

Table 3-2 Mechanical parameter of plastic fiber shotcrete

Compressive strength fc'(MPa)	Tensile Strength (MPa)	Elastic modulus Ec (MPa)	Unit Weight (kN/m^3)	Poisson ratio
25	2.5	23500	24.0	0.2

4 Initial Proposed Supports

4.1 Support of Excavation Class

The initial proposed supports for each rock type are shown in Table 4-1.

Table 4-1 Initial proposed supports for each rock type

Item	Unit	Initial proposed supports	
		II	III
Shotcrete thickness	mm	80	150
Shotcrete strength	MPa	25	25
Rock dowel length	m	6.0	6.0
Rock dowel spacing within each row	m	2.5	1.5
Rock dowel row spacing	m	2.5	1.5

4.2 Safety Factor

The support safety factor for shotcrete is 1.2.

The minimum safety factor for wedges analysis is 2.0.

5 Model Set-up, Boundary and Loading Conditions, Stress Initiation

For the case of gravitational loading, only, boundary and loading conditions to be set as shown below. The lower boundary of the counted domain is fixed in the X and Y directions, two lateral boundaries fixed in the X direction but unconstrained in the Y direction, and the top is free. The load of overburden above the top boundary is automatically applied by the software according to the elevations. Initial stress conditions in the model can be calculated by gravitational loading, or by specifying the relative ground surface elevation.

The finite element model for rock class II and III is shown as Figure 5-1, and the corresponding gravitational loading is shown in the Table 5-1.

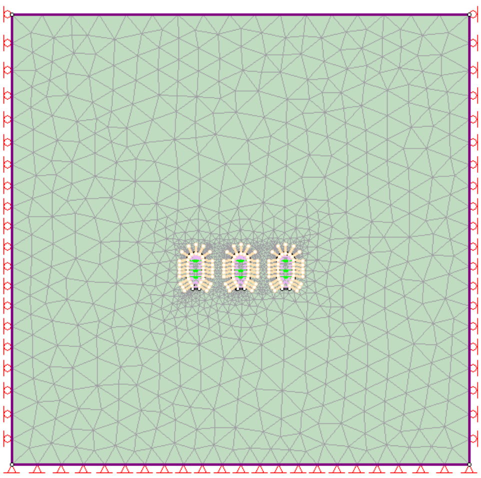

Figure 5-1 Finite element model and boundary conditions

Table 5-1 gravitational loading for surrounding rock

Rock class	Buried depth	Rock unit weight	Overburden gravitational loading
	m	kN/m ³	MPa
II	159.6	27	4.3
III	159.6	26.5	4.22

6 Calculation Results

6.1 Rock class II

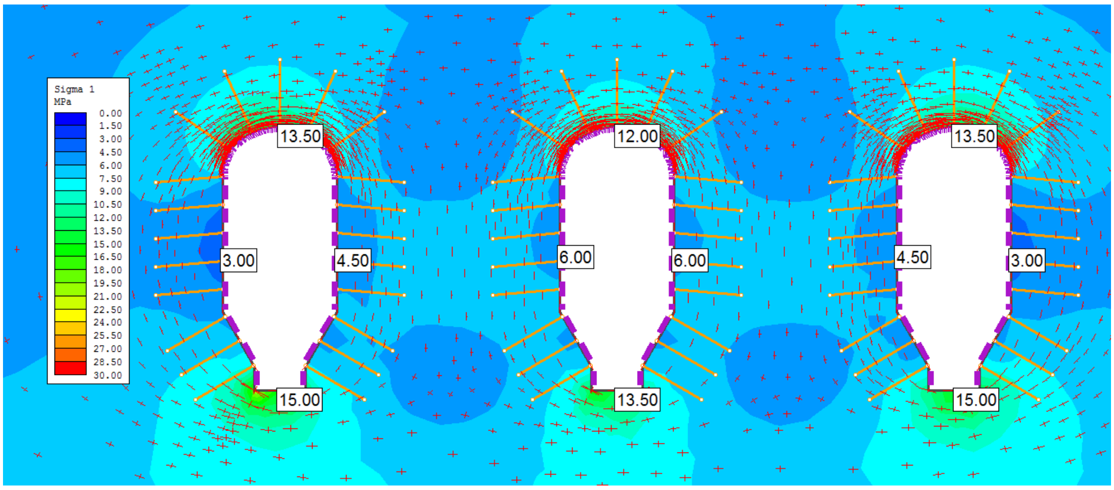

Figure 6-1 Surrounding rock first principal stress (Rock Class II)

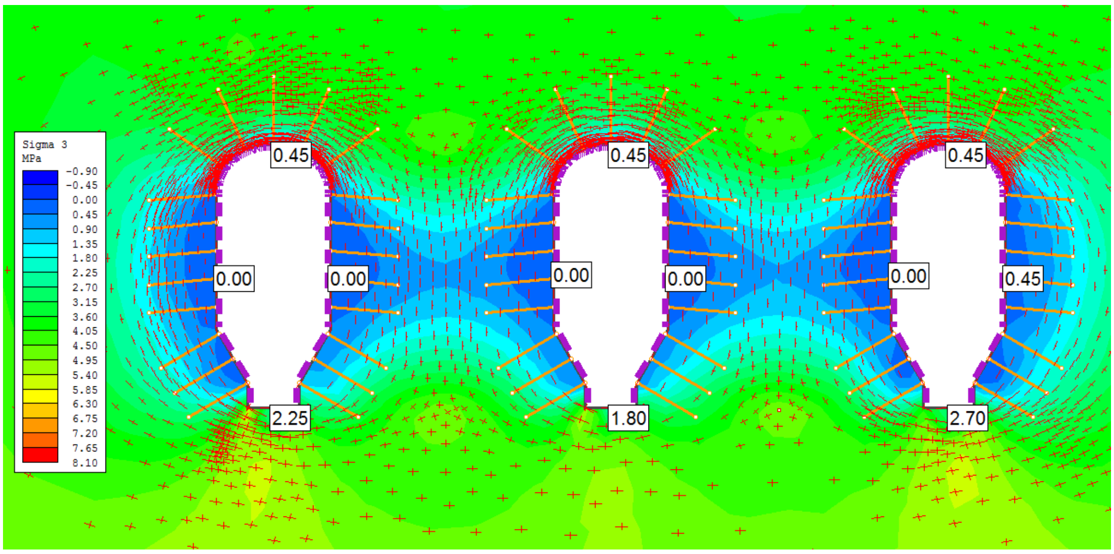

Figure 6-2 Surrounding rock third principal stress (Rock Class II)

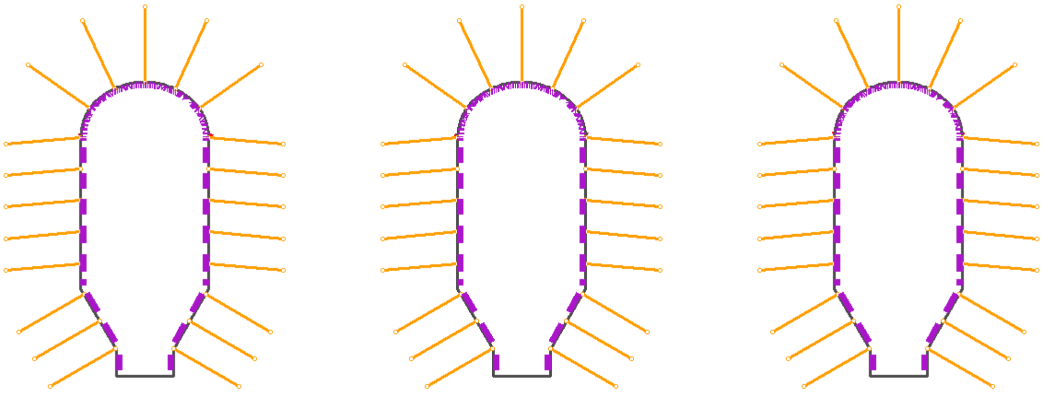

Figure 6-3 Surrounding rock plastic zone (Rock Class II)

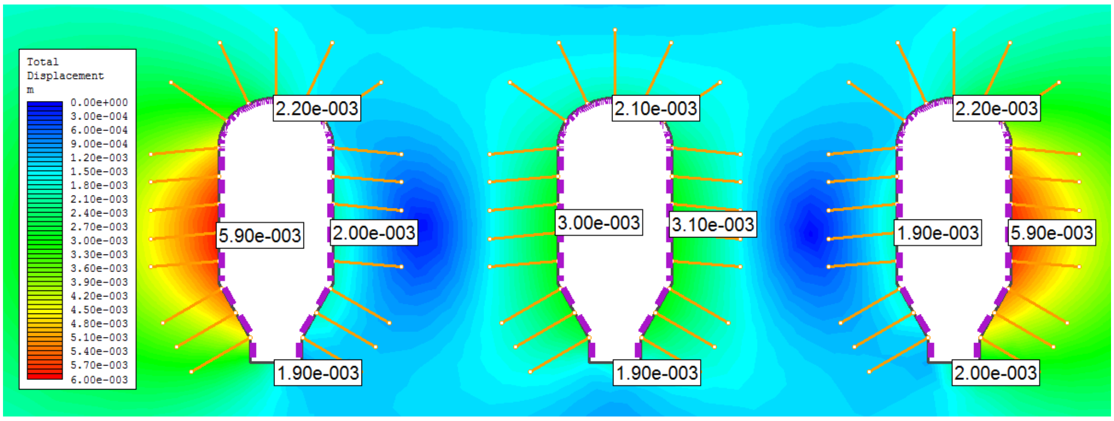

Figure 6-4 Surrounding rock displacement (Rock Class II)

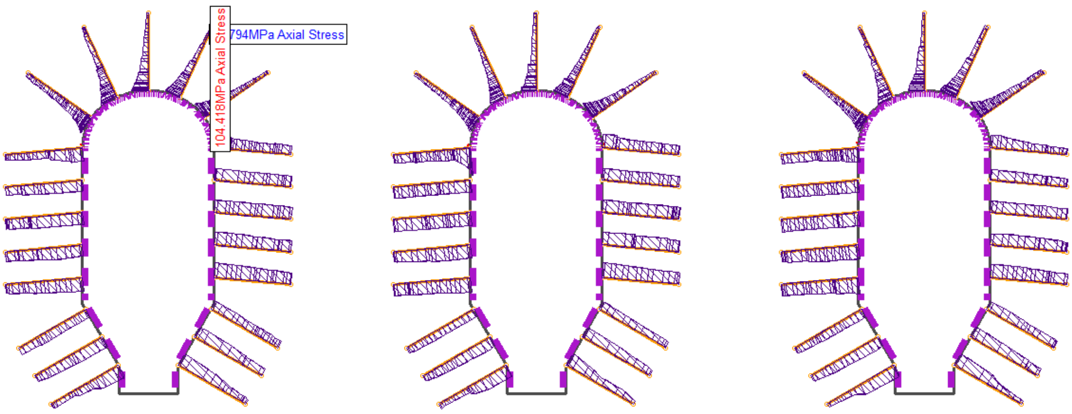

Figure 6-5 Rock dowel stress (Rock Class II)

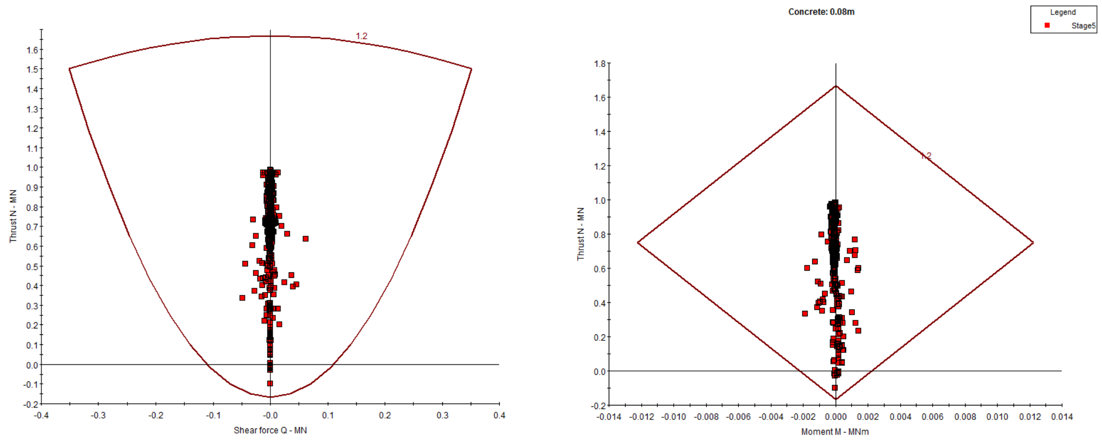

Figure 6-6 Bearing capacity of shotcrete (Rock Class II)

6.2 Rock class III

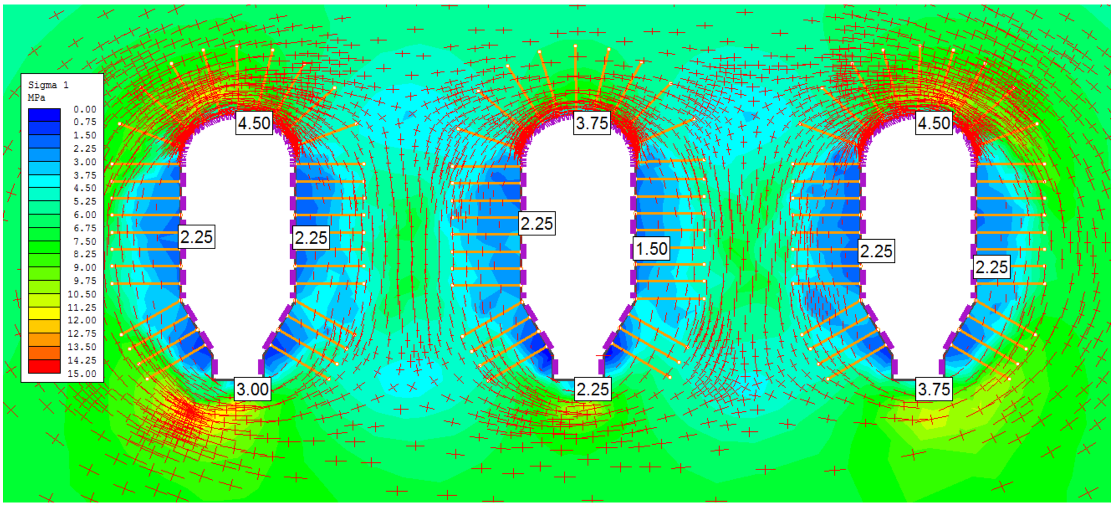

Figure 6-7 Surrounding rock first principal stress (Rock Class III)

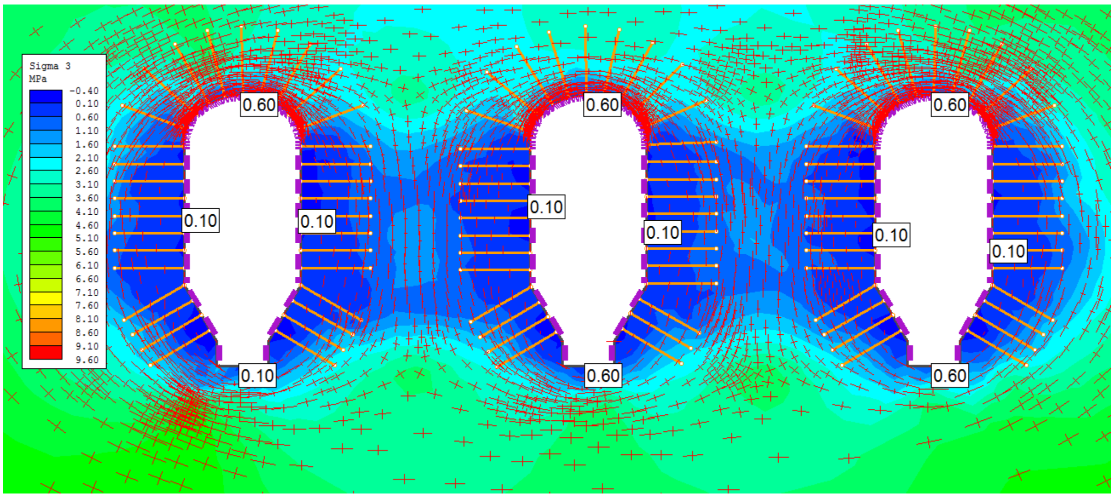

Figure 6-8 Surrounding rock third principal stress (Rock Class III)

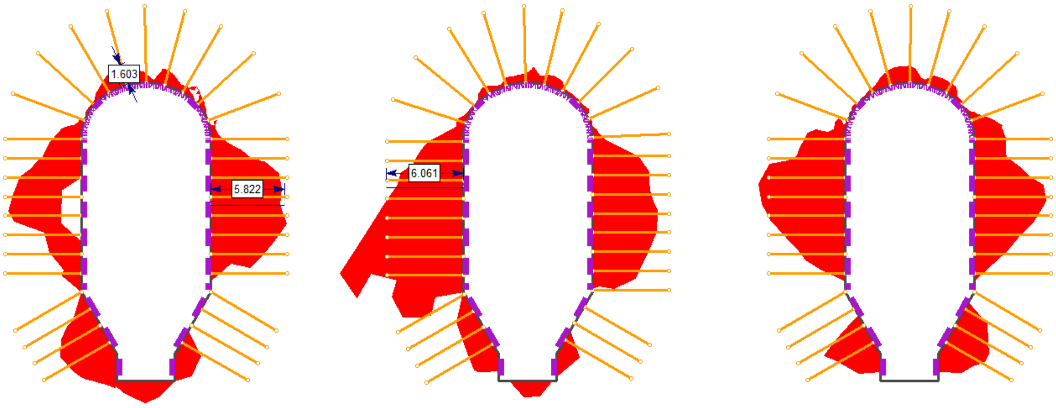

Figure 6-9 Surrounding rock plastic zone (Rock Class III)

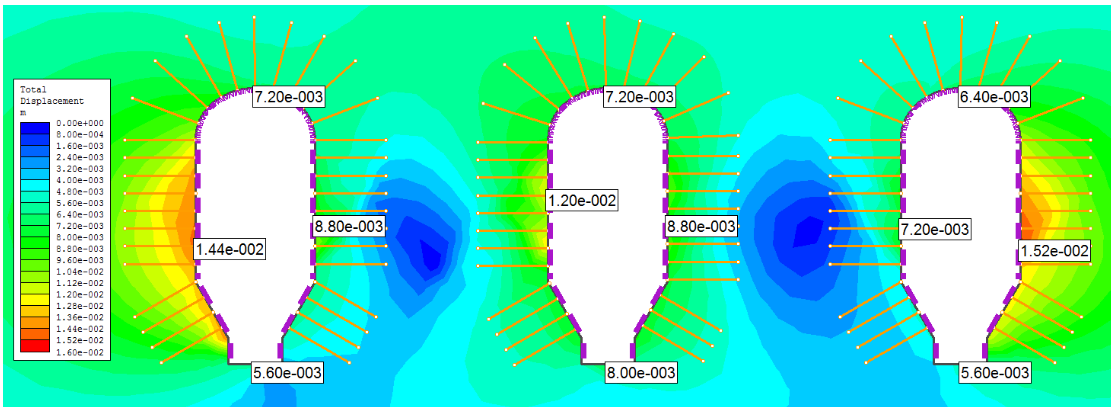

Figure 6-10 Surrounding rock displacement (Rock Class III)

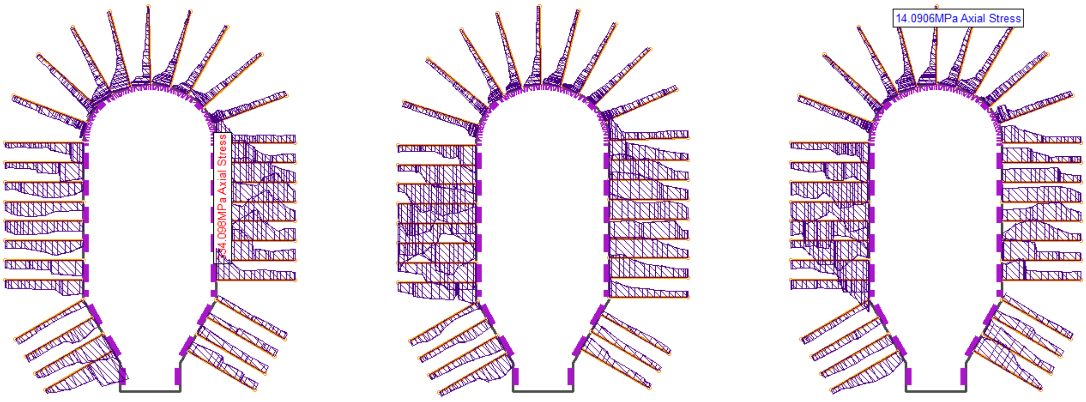

Figure 6-11 Rock dowel stress (Rock Class III)

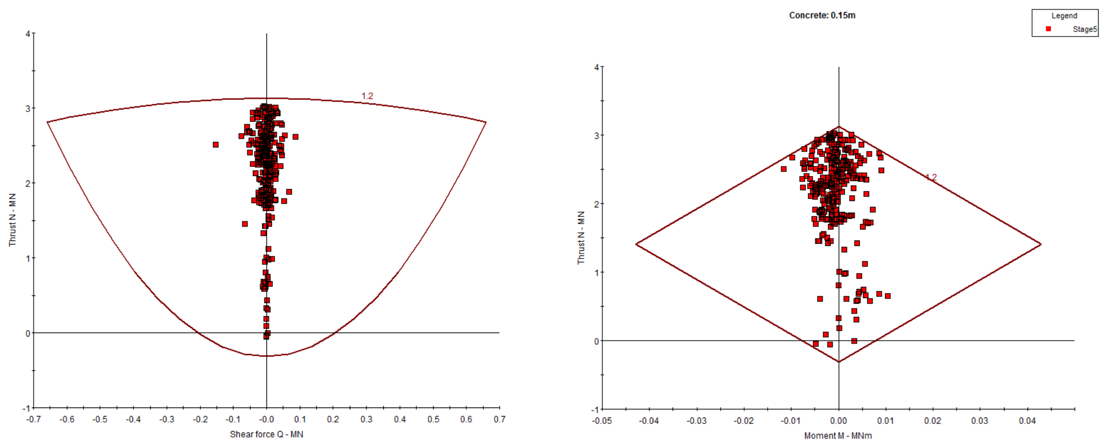

Figure 6-12 Bearing capacity of shotcrete (Rock Class III)

7 Wedge Analysis

7.1 Discontinuity Input Data

According to the site investigation, there are three group joints may distribute in the working section of desander basin, as is shown in Table 7-1. The stereographic projection of these joints in rock mass in shown in Figure 7-1. The Mechanical parameter of joints is shown in Table 7-2.

Table 7-1 Occurrence of joints in the desander basin

Joint NO.	Dip Direction	Dip	desander basin Direction(Trend)
J1(foliation)	205°	65°	52.18
J2	340°	25°	
J3	177.5°	70°	

Table 7-2 Mechanical parameter of joints in the desander basin

JONIT TYPE	JRC	JCS (MPa)	C (MPa)	Φ (°)
Foliation(J1、J3)	6	70	0.20	35.0
lithoclasts cemented (J2)	8	50	0.15	28.8

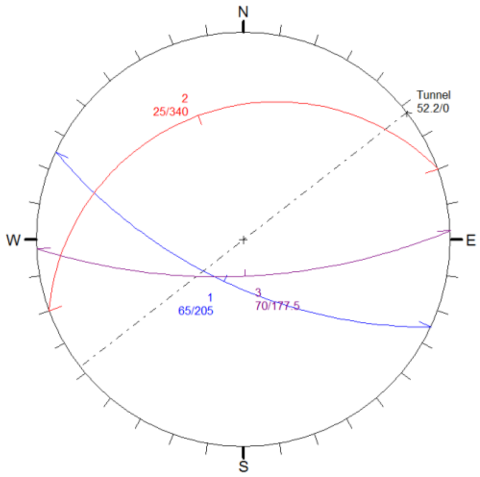

Figure 7-1 Stereographic projection of the joins in the desander basin

7.2 Wedge Stability Analysis

According to the wedge stability analysis, 6 potential wedge may occur in the excavation periods, which are shown in Figure 7-2 ~Figure **7-5**.

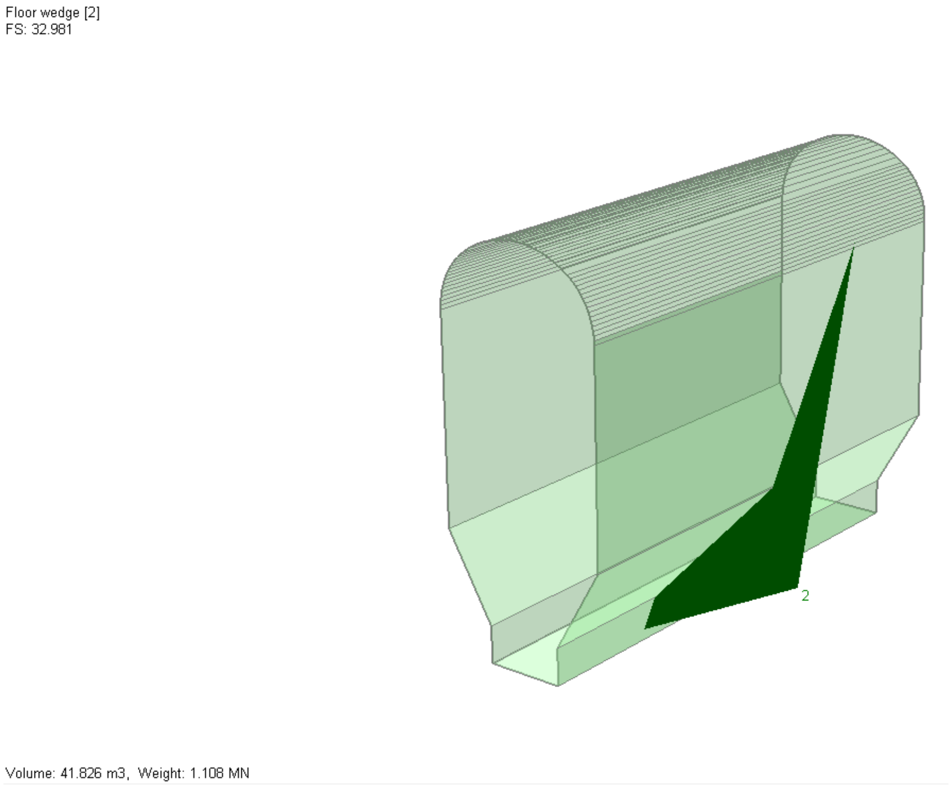

Figure 7-2 Potential wedge at floor

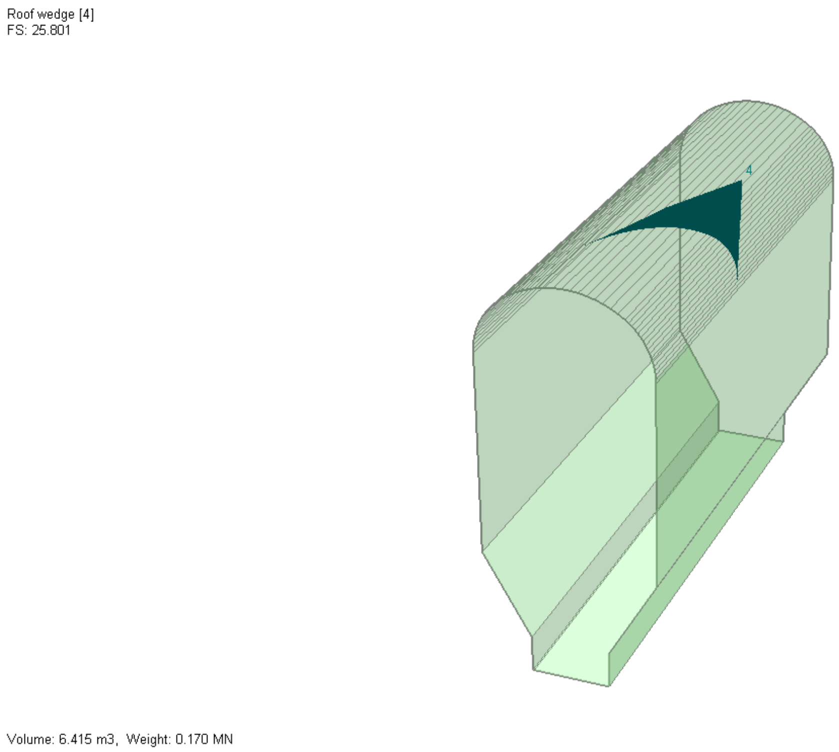

Figure 7-3　Potential wedge on the roof

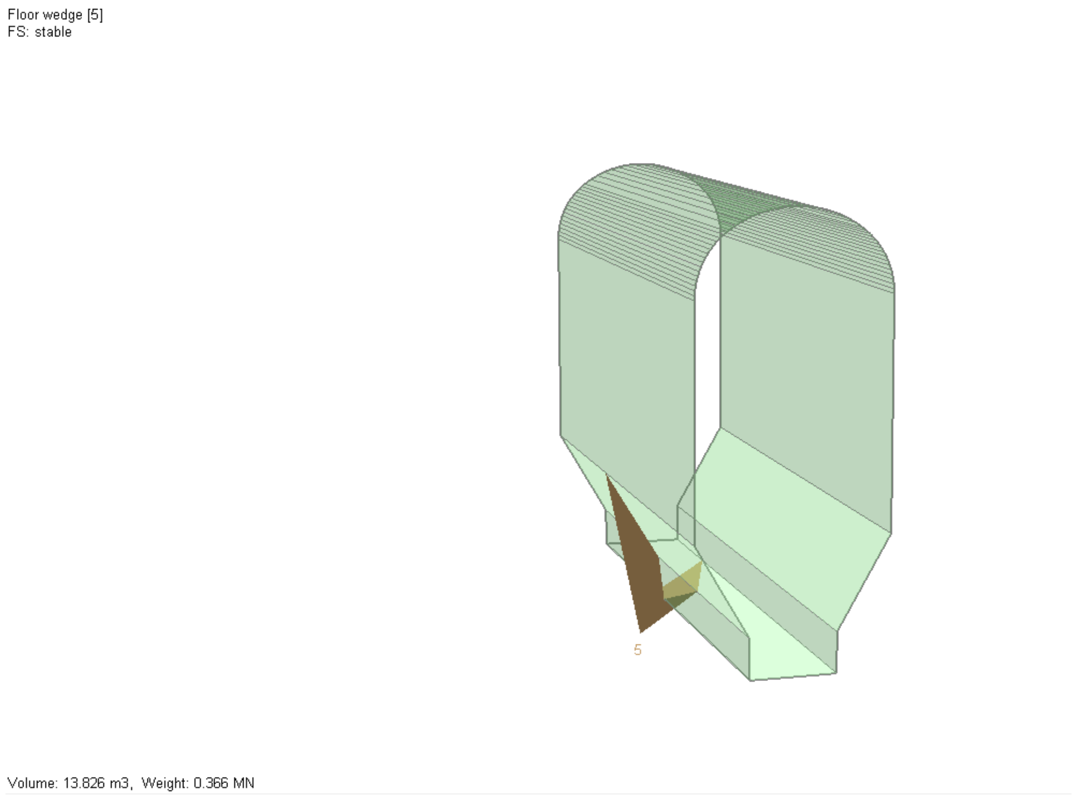

Figure 7-4　Potential wedge at floor

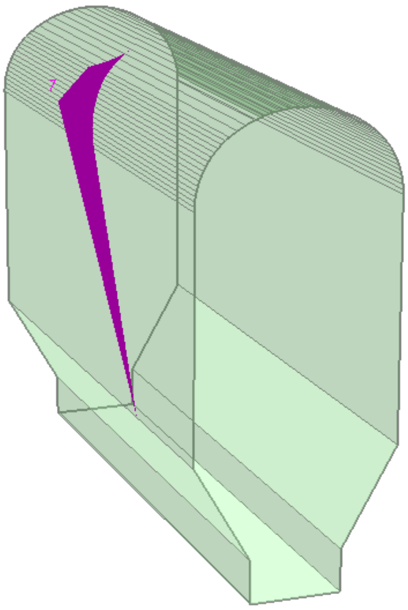

Figure 7-5 Potential wedge on upper left

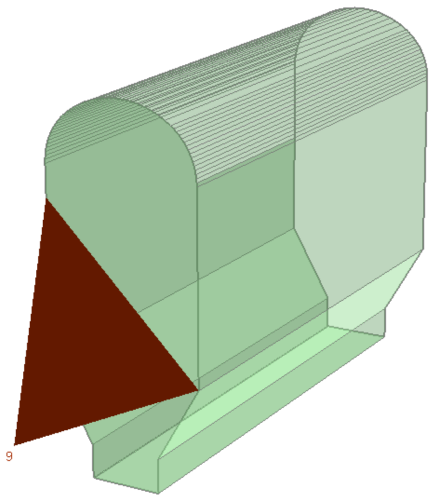

Figure 7-6 Potential wedge near end

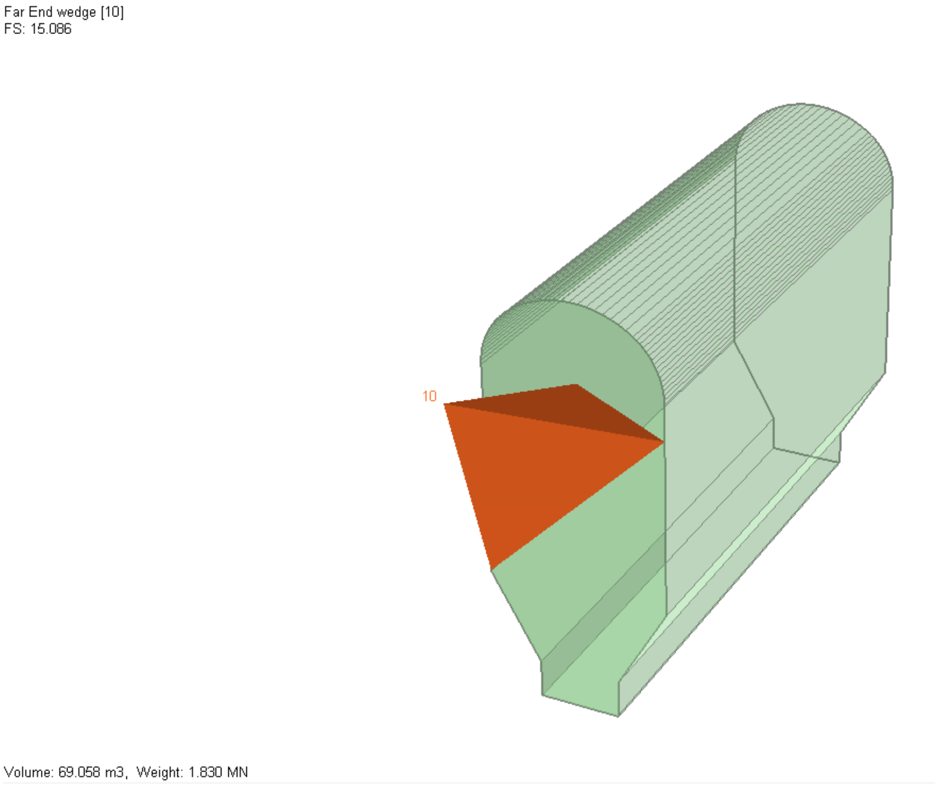

Figure 7-7 Potential wedge on upper right

It could be drawn from the calculation results that the minimum safety factor of potential wedges without supports in desander basin is 15.09 which is bigger than the minimum safety factor of 2.0.

8 Conclusions

(1) For rock class II, the full cross-section of the desander basin cavern is under compressive stress, to the maximum compressive stress value of 15.0MPa, occurred at invert of cavern, less than the rock's comprehensive strength; there is almost no plastic zone; magnitude of surrounding rock displacement is small, and maximum displacement is 5.9mm, which is 0.05% of desander basin span; maximum rock dowel stress is 104.4MPa, tensile stress is less than allowable strength of rock dowel; bearing capacity of plastic fiber shotcrete meets requirement of safety factor.

(2) Proposed supports for rock II is reasonable and meet requirement of cavern stability.

(3) For rock class III, the full cross-section of the desander basin cavern is under compressive stress, to the maximum compressive stress value of 4.5MPa, occurred at arch crown of cavern, less than the rock's comprehensive strength; plastic zone depth of outer side walls is about 6.0m; magnitude of surrounding rock displacement is not large, and maximum displacement is 15.2mm, which is 0.14% of desander basin span; rock dowel stress of inner side walls is greater than other area, maximum rock dowel stress is 333.4MPa, tensile stress is less than allowable strength of rock dowel; bearing capacity of plastic fiber shotcrete meets requirement of safety factor.

(4) Proposed supports for rock III is reasonable and meet requirement of cavern stability.

(5) For wedge analysis, the minimum safety factor of potential wedges without supports in desander basin is bigger than the minimum safety factor.